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Technical Note **LIGO-TXXXXXXXX-XX** Date: 2017/09/13

AS72 measurement and simulation comparsion

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1 MEASUREMENT IN PHYSICAL UNITS

The measured sensing matrix in physical units is shown below (under nominal 300mW ITMX CO2 laser power):

Table 1: Sensing matrix [W/rad]

		A_I	A_Q	B_I	B_Q
AS36	SRM	0.28	-0.62	-2.4	-0.73
	BS	76	1800	960	630
AS72	SRM	-0.0065	0.0042	0.0024	0.0017
	BS	-0.22	-0.43	-0.68	-0.72

To arrive at these values, we assumed the following calibration factors.

On the actuator side, the calibrations are

$$K_{\rm SRM} = 4.3\times10^{-11}[{\rm rad/ct}]\times\left(\frac{8.125{\rm Hz}}{f}\right)^2,$$
$$(={\rm SUS-SRM\_M3\_DRIVEALIGN\_P2P\_OUT\ in\ ct\ to\ SRM\ pitch\ angle\ in\ rad}), \tag{1}$$

for SRM. This value is calculated based on the WIT channel response and is almost 8 times greater than the theoretical value from [1]. The excitation frequency is at 8.125Hz, so all the values are scaled to that specific value.

For BS we have

$$K_{\rm BS} = 3.9\times10^{-13}[{\rm rad/ct}]\times\left(\frac{8.125{\rm Hz}}{f}\right)^4,$$
$$(={\rm SUS-BS\_M2\_DRIVEALIGN\_P2P\_OUT\ in\ ct\ to\ BS\ pitch\ angle\ in\ rad}), \tag{2}$$

Note that as we dithered BS in pitch, a factor of $\sin(\pi/4)$ is included in the OSEM2EUL conversion to account for this geometrical effect. This is calculated based on [2] and is consistent with the measured BS OPLEV response.

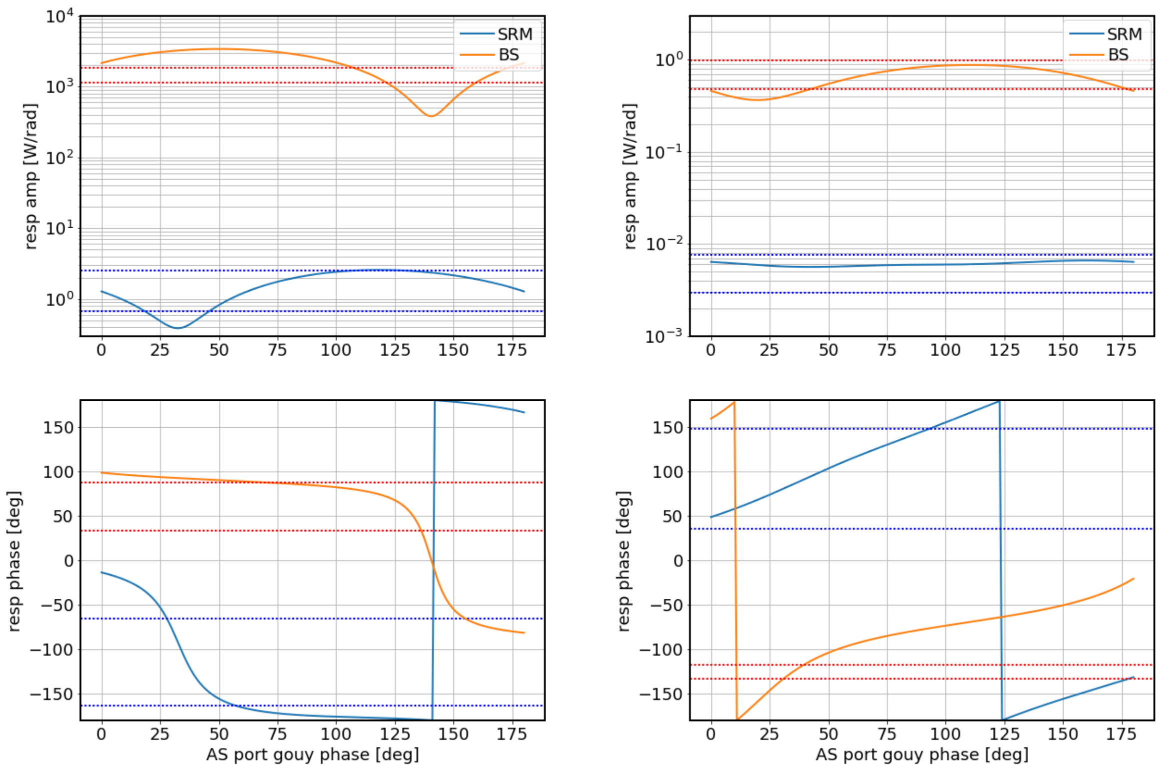
On the sensor side, our results are based on [3]. The numerical values for the sensors are

$$S_{\rm AS36\_A} = 1.5\times10^8[{\rm ct/W}], \tag{3}$$
$$S_{\rm AS36\_B} = 2.2\times10^8[{\rm ct/W}], \tag{4}$$
$$S_{\rm AS72\_A} = 1.5\times10^8[{\rm ct/W}], \tag{5}$$
$$S_{\rm AS72\_B} = 1.5\times10^8[{\rm ct/W}]. \tag{6}$$

For the 36MHz sensors, the values are based on the Table 3 in [3], with a factor of -6dB (-3dB) for difference in whitening gain for A (B) sensor and a factor of 2.8/4.0 for digital gain. For the 72MHz sensors, they are factor of 1/16 weaker in optical response [4], 1/2.8 smaller gain in the filter module, but have 33dB extra whitening gain relative to the 36MHz ones.

2 COMPARISON WITH SIMULATIONS

We compare the measurements to Finesse[5] simulation, assuming modulation depth of $\Gamma_{9.1} = \Gamma_{45.5} = 0.22$ rad, and $\Gamma_{118.3} = 0.15$ mrad [6]. The results are shown below in Figs. 1 and 2 for two scenarios with different ITM thermal lensing configuration. The solid curves are from the simulation (treated as a function of A sensor's gouy phase at the AS port), and the dotted lines are measured values for A and B sensors, respectively.



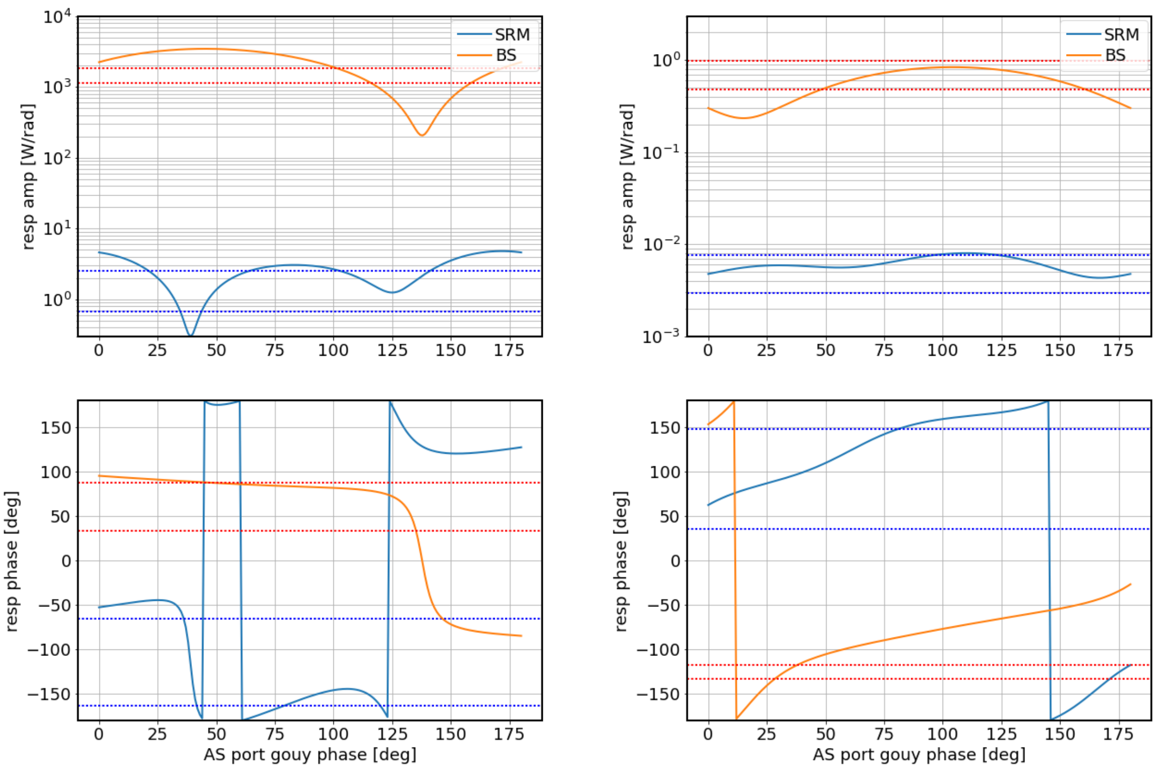
(a) AS36 response. (b) AS72 response.

Figure 1: Comparison between simulation (solid curves) and measured values (dotted lines). Nominal SRC one-way gouy phase of 18° without ITM differential thermal lens.

The simulation, at least in terms of the signal amplitude, is consistent with measurement.

3 ROBUSTNESS

According to Table 1, a possible implementation of AS72 scheme is to use AS72_A_Q for SRM and AS72_B_Q for BS control. To demonstrate its robustness, we plot its fractional changes at different ITMX CO2 laser powers in Fig. 3. As



(a) AS36 response.

(b) AS72 response.

Figure 2: Same as Fig. 1 but extra 200km of ITMX thermal lens is added.

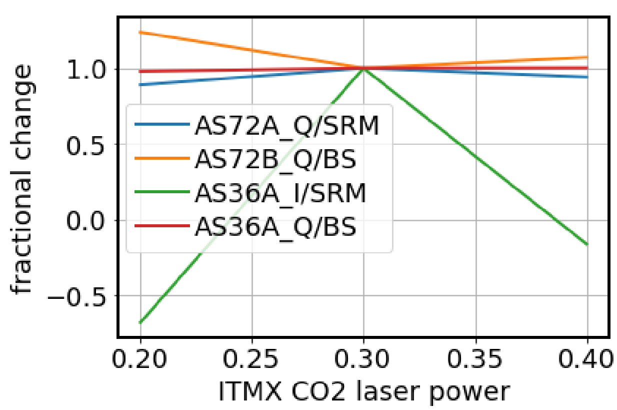
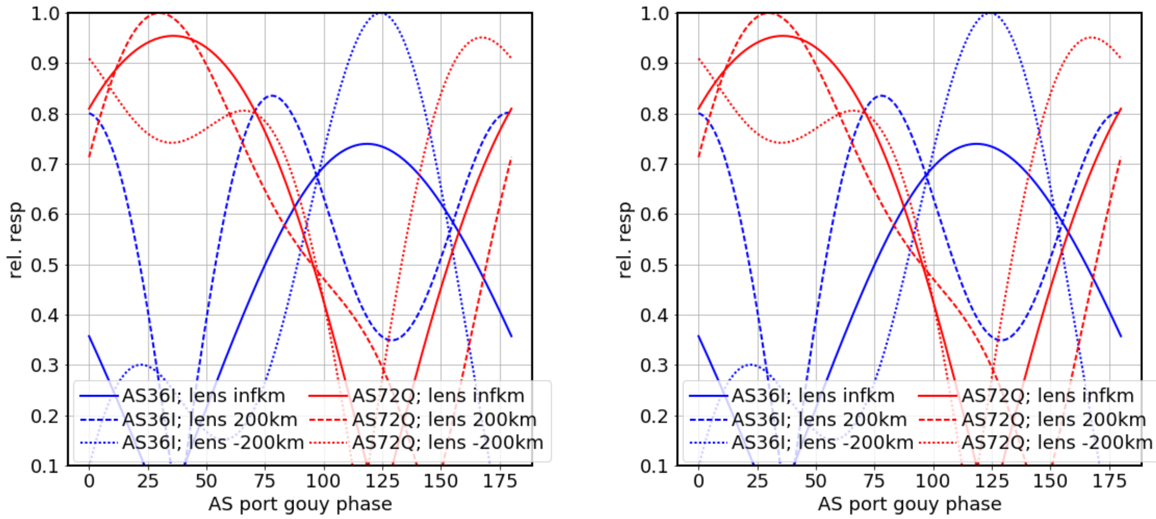


Figure 3: Measured fractional variation of the signals. The AS72_A_Q signal for SRM control sees much less change compared to AS36_A_I which is currently used.

In Fig. 4 we show how the SRM ASC signal changes in simulation. Two schemes are considered: using AS36_I (blue) and AS72_Q (red). The robustness of the AS72 scheme can be further improved if we increase the



(a) $T_{\rm SRM} = 0.37$ (b) $T_{\rm SRM} = 0.32$

Figure 4: Simulated fractional change

4 NOISE PERFORMANCE

From the simulation we have 3mW of power incident onto the AS WFS, leading to a shot noise level of $0.034\text{nW}/\sqrt{\text{Hz}}$. Inverting the sensing matrix in Table 1, and assigning the matrix conditional number κ to SRM, we then arrived at the shot-noise limited sensitivity

$$x_{\rm SRM} \simeq 2.4\ \text{nrad}/\sqrt{\text{Hz}}\left(\frac{\kappa}{3}\right)\left(\frac{0.15\text{mrad}}{\Gamma_{\rm RF118.3}}\right)\left(\frac{3.0\text{mW}}{P_{\rm ASWFS}}\right)^{1/2}, \tag{7}$$

$$x_{\rm BS} \simeq 0.047\ \text{nrad}/\sqrt{\text{Hz}}\left(\frac{0.15\text{mrad}}{\Gamma_{\rm RF118.3}}\right)\left(\frac{3.0\text{mW}}{P_{\rm ASWFS}}\right)^{1/2}, \tag{8}$$

where we have assumed that the AS WFS power is always dominated by the RF45.5 SBs, so increasing the RF118.3 modulation depth will only increase the amount of signal without causing extra shot noise. The matrix condition number κ is assigned all to SRM to minimize the BS noise.

References

[1] https://dcc.ligo.org/LIGO-T1000061.

[2] https://dcc.ligo.org/LIGO-T1100479.

[3] https://dcc.ligo.org/LIGO-T1600136

[4] https://dcc.ligo.org/LIGO-T1300488

[5] http://www.gwoptics.org/finesse/

[6] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=37061

[7] https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=30830